

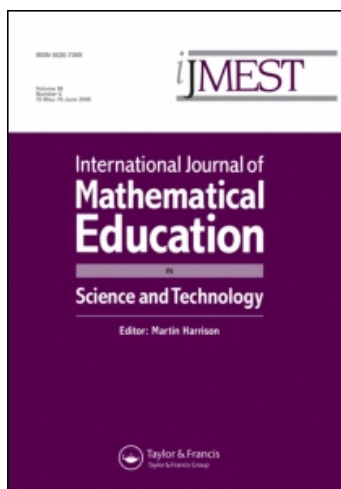
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Publisher Taylor & Francis

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International Journal of Mathematical Education in Science and Technology

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713736815>

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To cite this Article Ross, John A. and Bruce, Catherine D. (2009) 'Student achievement effects of technology-supported remediation of understanding of fractions', *International Journal of Mathematical Education in Science and Technology*, 40: 6, 713 – 727

To link to this Article: DOI: 10.1080/00207390902971999

URL: <http://dx.doi.org/10.1080/00207390902971999>

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Student achievement effects of technology-supported remediation of understanding of fractions

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(Received 30 September 2008)

Students have difficulty learning fractions, and problems in understanding fractions persist into adulthood, with moderate to severe consequences for everyday and occupational decision-making. Remediation of student misconceptions is hampered by deficiencies in teachers' knowledge of the discipline and pedagogical content knowledge. We theorized that a technology resource could provide the sequencing and scaffolding that teachers might have difficulty providing. Five sets of learning objects, called CLIPS (Critical Learning Instructional Paths Supports), were developed to provide remediation on fraction concepts. In this article, we describe one stage in a research program to develop, implement and evaluate CLIPS. Two studies were conducted. In Study 1, 14 grade 7–10 classrooms were randomly assigned, within schools, to early and late treatment conditions. A pre-post, delayed treatment design found that CLIPS had no effect on achievement for the Early Treatment group due to unforeseen implementation problems. These hardware and software issues were mitigated in the late treatment in which CLIPS contributed to student achievement (Cohen's $d = 0.30$). Study 2 was a pre-post, single group replication involving 18 grade 7 classrooms. The independent variable was the number of CLIPS completed. Completion of all five CLIPS contributed to higher student achievement: Cohen's $d = 0.53$, compared to students who completed none ($d = 0.00$) or 1–4 CLIPS ($d = 0.02$). The two studies indicate that a research-based set of learning objects is effective when the full program is implemented. Incomplete sequences deprive students of instruction in one or more constructs linked to other key ideas in the conceptual map and reduce the amount of practice required to remediate student misconceptions.

Keywords: learning objects; fractions; student achievement

1. Introduction

Fractions have long been described by educational researchers as a challenging area of the curriculum for students in mathematics (e.g. [1–3]). The failure to master simple fraction tasks can have serious consequences, for example:

A newly graduated registered nurse... administered one-half grain of morphine when, in fact, one-eighth grain was ordered, reasoning that since 4 plus 4 equals 8, $1/4$ plus $1/4$

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equals $1/8$ (instead of $1/2$). Although the patient survived, the dose was enough to depress her respiration to a life threatening level. This was not an isolated incident... [4, p. 168].

In this article, we argue that many students emerge from elementary school (i.e. kindergarten to grade 8 or age 4–14 years) with insufficient knowledge of fractions to complete tasks routinely encountered by adults. We will describe a set of learning objects designed to provide remediation in fractions and report the results of field tests involving three samples of students in grades 7–10 (age 13–16 years). The research reported here is part of a multi-year project to develop, implement and assess learning objects for core objectives in mathematics.

2. Literature review

2.1. Evidence of low achievement on fractions

The challenge of learning fractions has been documented in case studies of middle school children [5,6]. Fractions are difficult to learn because they require deep conceptual knowledge of part-whole (how much of an object or set is represented by the fraction symbol), measurement (fractions are made up of numbers that can be ordered on a number line) and ratios [7]. A representative national US sample found that only one-third of 13-year-old students were able to correctly place a simple fraction on a number line, a learning objective for 11-year-olds [6]. Manipulating fractions is particularly difficult when embedded in word problems. Boaler [8] found that 12–13-year-old students in a school with a traditional math curriculum had difficulty in recognizing the math when simple tasks requiring the comparison of fractions were presented in a context-laden form. Students in a school committed to teaching for deep understanding were more likely to find context enabling, although the overall performance in both schools was poor.

2.2. Importance of fractions in post-school experience

School success in mathematics contributes to higher earnings. A national longitudinal study found that after controlling for the effects of number of years in school, adults with stronger mathematics skills (including fractions) had significantly higher wages than adults with lower mathematics achievement [9]. The effects increased from the 1970s to the 1980s in response to increased employer demand for basic cognitive skills. The importance of fractions in blue collar occupations was demonstrated in an observational study of jobs in a car plant [10]. The most important occupational demands for knowledge of fractions is for nurses and pharmacists dispensing medications, especially in paediatrics where fractional doses are the norm [11], as noted in the quotation that opened this article. In a contrary view, Hoyles *et al.* [12] provided ethnographic evidence that paediatric nurses invent algorithms specific to particular medications that preclude the need for mathematical understanding.

In addition to occupational requirements, knowledge of fractions is required in everyday decision-making, such as self-monitoring medication doses. Less numerate individuals have poorer medical outcomes when their treatment requires following complicated medication instructions [13].

Low performance on fraction tasks continues into adulthood. The National Adult Literacy Study found that almost twice as many adult Americans (22%) scored below basic on numeracy tasks that included fractions than on other literacy dimensions [14], a finding also reported in other studies [15]. Skilled professionals are not exempt: low scores on simple fraction tasks have been reported for the samples of nurses [16,17] and pharmacy students [4].

The continuation of low performance on fraction tasks into adulthood can be attributed to curriculum priorities in schools. Students who fail to learn fractions in elementary school have little opportunity to acquire these skills in high school because the mathematics curriculum is so crowded. This is particularly the case in Ontario, the province where our research was conducted, because 5 years of high school were compacted into 4 beginning in 1999.

2.3. *Why create a technology resource?*

Teachers' ability to identify the conceptual origins of student difficulties, predict misconceptions and relate current to future curriculum topics is enabled by their disciplinary and pedagogical content knowledge [18,19]. Generalist teachers in elementary schools and high school teachers assigned mathematics classes outside their specialization might not have had the opportunity to develop the conceptual foundations required to promote deep understanding of fractions. Previous studies found evidence of generalist teacher confusion around core fraction concepts [20–22]. We theorized that a technology resource could provide additional support to teachers in the form of sequencing and scaffolding. Scaffolding in this context consists of learning materials that provide temporary support to enable a student to achieve a desired performance. With sequenced practice, the amount of scaffolding required for success is gradually reduced and the student is able to perform independently [23]. In addition, having a resource that students could complete relatively independently of teacher guidance might increase teacher willingness to provide remediation to students who need it.

3. CLIPS

Critical Learning Instructional Paths Supports (CLIPS) are multi-media learning objects focused on fractions. The term CLIPS was coined by Hill and Crévola as 'devices for bringing expert knowledge to bear on the detailed daily decisions that every teacher must make in teaching a coherent domain of the curriculum' [24, p. 56]. The Ontario Ministry of Education applied the term CLIPS to a series of software programs for students needing additional support for learning fractions. To view the fractions CLIPS, go to: <http://oame.on.ca/CLIPS/index.html>.

Students begin by viewing a video which shows why students should care about fractions. Students are presented with a menu of five sets of activities: (i) representing simple fractions, (ii) forming and naming equivalent fractions, (iii) comparing simple fractions, (iv) forming equivalent fractions by splitting or merging parts and (v) representing improper fractions as mixed numbers. Within each set of activities there are introductory instructions, interactive tasks, consolidation quizzes and extension activities. The CLIPS are designed as a research-based sequence of lessons

of 15–20 min per day for 5 days, but each can stand alone and teachers may assign less than 5 on the basis of their assessment of student needs.

For example, CLIPS A has an introduction activity on representing simple fractions. There is a voice over with area models presented on the screen. In the second activity, students are asked to describe a fraction by entering the numerator and denominator and showing what the fraction looks like in an area model. There are three additional mini-sets of activities. The student is given a quiz on representing simple fractions. Students drag their answers to a box and receive immediate feedback. If incorrect, they are given an explanation. The final component of CLIPS A is a ‘show what you know’ screen, which suggests five different activities (e.g. a fractions card game) that students could do as consolidation. The same structure is repeated for each of the five CLIPS.

4. Purpose of the study

The research program was an extended-term mixed-method design [25] involving four stages. (1) We conducted a systematic needs assessment [26] which combined student performance data, student beliefs about their mathematical competencies and teacher perceptions about the difficulty and importance of learning particular fraction objectives. The needs assessment provided a rank-ordered list of the most urgent student learning needs. (2) This list was transformed into an integrated learning agenda that prescribed an instructional sequence designed to overcome student deficits. A design team drew upon research on teaching fractions (particularly [27–29]) to develop interactive activities addressing each learning need. (3) The CLIPS were pilot tested in two classrooms to assess their functioning and to generate detailed recommendations for their revision [30]. (4) The CLIPS were revised on the basis of qualitative data collected in the pilot test and field tested (the research reported here). The purpose was to measure the effects of CLIPS on student achievement in conditions approximating normal use. The research question was: did CLIPS contribute to students’ understanding of fractions?

5. Study 1

5.1. Research design

In Study 1, grade 7–10 classrooms were randomly assigned, within schools, to early and late treatment conditions as shown in Table 1. Teachers selected the students they believed would benefit from CLIPS (see below). These students were tested on three

Table 1. Research design for Study 1.

Early Treatment ($N=44$)	O_1	X_{CLIPS}	O_2		O_3
Late Treatment ($N=47$)	O_1		O_2	X_{CLIPS}	O_3

Notes: O_1 = Test occasion 1 consisting of six fraction items and a battery of affect measures.

O_2 = Test occasion 2 consisting of 16 fraction items.

O_3 = Test occasion 3 consisting of 16 fraction items.

occasions. Occasions 1 and 2 compared the early CLIPS group to a control group, i.e. students who had been selected for CLIPS but had not received the treatment. Occasions 2 and 3 compared the late CLIPS group to the early group that was not using CLIPS at the time. All teachers who volunteered for the project had equal opportunity to implement CLIPS, thereby avoiding demoralization of the control group and denial of treatment to students who could benefit from it. Since teachers, not researchers, selected the students who received CLIPS, the design was quasi-experimental, requiring a demonstration that the groups were equivalent on entry.

5.2. Study 1 participants

In Study 1, 14 grade 7–10 teachers from one public school district in Ontario, Canada, volunteered to participate. The district served a student population in which 98% were Canadian born, only 1% spoke a language other than English at home, 24% were identified as having special needs, and average family income in the district was near the mean for the province of Ontario. Classrooms were randomly assigned, in schools, to the early and late treatment groups. Teachers used the results of the first test occasion and their knowledge of students to identify 91 of their 364 students (25%) for CLIPS training.

5.3. Study 1 data sources

Student achievement was measured on three occasions. Test 1 consisted of six fraction items drawn from the PRIME placement tests for number and operations [31]. Tests 2 and 3 each consisted of 16 items generated for the study. The items included procedural tasks, e.g. ‘Write two fractions that are equivalent to $5/9$ ’ and conceptual, e.g. ‘ $2/10$ is less than $2/5$. How do you know?’ All items were scored 0–2 by trained markers. Inter-rater reliability, based on samples of 200, 210 and 210 items for the three test occasions was high. Perfect agreement was 93%, 96% and 94% and chance adjusted agreement was $\kappa = 0.86$, 0.92 and 0.88, respectively. Student achievement was operationalized at each test occasion as the mean item score.

At Test 1 occasion we administered a battery of affect measures to determine the equivalence of the early and late treatment groups. *Math self-efficacy* consisted of eight Likert items measuring expectations about future mathematics performance (from Ross *et al.* [32], e.g. ‘as you work through a math problem how sure are you that you can . . . explain the solution’). There were six response options, anchored by ‘not sure’ and ‘really sure’.

Functional beliefs about mathematics learning consisted of five statements about participating in mathematical discussions from Jansen [33] and Schoenfeld [34]. The items were Likert scales, e.g. ‘If you are there throwing out your ideas, you could find a new way of doing a math problem’ with six response options, anchored by ‘strongly agree’ and ‘strongly disagree’.

Dysfunctional beliefs about mathematics learning consisted of eight items from Schommer-Aitkins *et al.* [35], measuring belief in quick/fixed learning (i.e. learning occurs quickly or not at all and that intelligence is fixed rather than incremental); e.g. ‘If I cannot understand something quickly, it usually means I will never understand it’. There were six response options, anchored by ‘strongly agree’ and ‘strongly disagree’.

Fear of failure consisted of six items (e.g. 'I worry a lot about making errors on my math work') from Turner *et al.* [36]. There were six response options, anchored by 'not at all true' and 'very true'.

Effort was measured with eight items from Ross *et al.* [32] (e.g. 'how hard do you study for your math tests?'). There were six response options, anchored by 'not hard at all' and 'as hard as I can'. Students also reported their gender and grade (7–10).

After administering CLIPS in their classrooms, teachers completed an implementation survey consisting of 12 open and fixed response items. The survey asked teachers how they assigned students to CLIPS, the amount of time spent on CLIPS, perceptions of the adequacy of time allotted, where students worked on CLIPS (e.g. the classroom, the library, at home), perceptions of student like/dislike of the program, perceptions of student success, difficulties in accessing CLIPS software and whether the teacher was able to resolve technical problems, strategies used by the teacher to interact with students while working with CLIPS and to debrief them after completion, whether teachers felt the right students had received CLIPS, whether they would use CLIPS again and fractions topics taught during CLIPS implementation. Teachers also indicated how many (0–5) CLIPS each student completed.

5.4. Teacher training

CLIPS were designed to be used with relatively little teacher training. Teachers who volunteered for the project received 60 min of instruction that focused on how to access the program (through disks or the web), hardware requirements, the structure of the five CLIPS and the projected benefits for students.

5.5. Study 1 analysis procedures

After establishing the reliability of the measures used in the study, we used *t*-tests to determine the equivalence of the early and late treatment groups. To assess the effects of CLIPS on the early treatment group, we conducted analysis of covariance (ANCOVA) (using GLM in SPSS 16.0) in which the dependent variable was posttest achievement O_2 , the covariate was pretest achievement O_1 and the independent variable was experimental condition (the early group that received CLIPS vs. the late group that did not). To assess the effects of CLIPS on the late treatment group, we conducted the ANCOVA in which the dependent variable was posttest achievement O_3 , the covariate was pretest achievement O_2 , and the independent variable was experimental condition (the late group that received CLIPS vs. the early group that did not).

5.6. Study 1 results

There were small amounts of achievement data missing completely at random [Little's MCAR test: $\chi^2 = 10.41$, $df = 6$, $p = 0.108$]: one case for achievement at O_1 and four cases at each of O_2 and O_3 . We used expectation maximization to impute missing values. We used the same procedure to replace a small number of missing values for the affect variables. All variables were normally distributed: skewness and

kurtosis were < 1.0 on all measures. Table 2 shows that the variables were reliable: internal consistency was $\alpha > 0.70$ for all variables.

The t -tests comparisons displayed in Table 2 indicate there were no statistically significant differences on O_1 achievement or on any of the attitude or demographic measures. In both groups there were more boys than girls: 57% of the students in the Early Treatment were male and slightly more, 66% in the Late Treatment were male. We interpreted these results to mean that the groups were equivalent prior to implementation.

We used data from students who did not complete any CLIPS ($N=273$) to determine whether the achievement tests were of equivalent difficulty. O_1 and O_2 were equivalent [$t(272) = -0.22, p = 0.824$]; the means (and standard deviations) were 1.52 (0.44) and 1.52 (0.39). The O_2 and O_3 were different [$t(272) = 3.62, p < 0.001$]; the mean item score (and standard deviation) for O_3 was significantly lower 1.45 (0.34) than the mean for O_2 .

We conducted a univariate ANCOVA using GLM in SPSS. In the first ANCOVA, the dependent variable was O_2 achievement, the covariate was O_1 achievement and the independent variable was study condition (early or late, i.e. exposure or no exposure to CLIPS). CLIPS had no statistically significant effect on student achievement for students in the Early Treatment group [$F(1, 88) = 0.122, p = 0.728$]. Although the model explained 47% of the achievement variance, virtually all the variance was attributable to the pretest score [$F(1, 83) = 7.873, p < 0.001$]. Students who performed poorly on the achievement pretest continued to perform poorly on the posttest, regardless of whether they had completed CLIPS.

Responses to the teacher survey revealed obstacles to CLIPS implementation. Technology concerns focused on both hardware and software. Hardware issues included: sound ('lost audio'), inability to launch the program ('CD ROMs

Table 2. Alphas, means, standard deviations and t -test comparisons for Early ($N=44$) and Late ($N=47$) Treatment groups in Study 1.

Variable	α	No. items	Group	Mean	SD	Comparison of means
Math self efficacy	0.88	8	Early	3.45	0.84	$t(89) = -1.41, p = 0.164$
			Late	3.71	0.89	
Beliefs about math	0.81	5	Early	3.58	0.81	$t(89) = -0.11, p = 0.916$
			Late	3.60	0.88	
Quick/fixed learning	0.94	8	Early	2.60	0.90	$t(89) = 0.15, p = 0.884$
			Late	2.57	1.03	
Fear of failure	0.81	6	Early	3.09	1.18	$t(89) = 0.35, p = 0.731$
			Late	3.00	1.20	
Effort	0.89	8	Early	3.94	1.14	$t(89) = -0.28, p = 0.784$
			Late	3.87	0.96	
Grade ^a		1	Early	2.00	1.08	$t(89) = 1.41, p = 0.257$
			Late	1.79	0.62	
O_1 achievement	0.75	6	Early	0.97	0.42	$t(89) = 1.57, p = 0.120$
			Late	0.82	0.49	
O_2 achievement	0.84	16	Early	0.96	0.38	$F(1, 88) = .122, p = 0.728$
			Late	0.88	0.50	
O_3 achievement	0.82	16	Early	1.03	0.35	$F(1, 88) = 4.71, p = 0.033$
			Late	1.10	0.42	

Note: ^aGrade: grade 7 = 1, grade 8 = 2, grade 9 = 3, grade 10 = 4.

on computers did not work') and sporadic problems running the program ('screen froze'). The diversity of hardware issues suggested that the system requirements of CLIPS pushed the limits of the hardware available in the schools. Software issues included: the web version of the program (as opposed to disk delivery) was so slow that students became discouraged, students were 'unable to open the disk', 'program did not run' and 'one disk did not work'. The lack of equipment in their homerooms and school policies that assigned computers to non-classroom locations meant that the majority of the students in the Early Treatment group accessed CLIPS outside their math classroom. In these non-classroom locations, students were either unsupervised (e.g. home use) or monitored for behaviour only (i.e. if students appeared to be working on the program, regardless of how, the librarian or supervisor of the computer room did not intervene). For further discussion of these implementation issues, see [30].

CLIPS had a positive impact on student achievement in the Late Treatment group. In the second ANCOVA, the dependent variable was achievement O_3 , the covariate was achievement O_2 and the independent variable was experimental condition. In this phase of the study, the Late Treatment received CLIPS and the Early Treatment did not. Students who received CLIPS between O_2 and O_3 had higher achievement than students who did not receive CLIPS during this time period [$F(1, 88) = 4.71, p = 0.033$]. CLIPS accounted for 5% of the achievement variance, Cohen's $d = 0.30$.

Figure 1 shows the achievement test means for the Early and Late Treatment groups at each test occasion. The means for students who were not assigned CLIPS are also displayed in the figure. Their means were substantially higher than the students identified by teachers as needing support in learning fractions (the non-CLIPS group obtained 73% of the maximum score across all three tests) and the non-CLIPS group declined from O_2 to O_3 , while the means from the two CLIPS groups improved. The most likely explanation for the decline in the scores of the non-CLIPS group was measurement error.

We re-ran the analysis to explore whether the number of CLIPS completed influenced achievement. We compared students who completed no CLIPS ($N = 273$) to those who completed 1–4 ($N = 65$) and all five CLIPS ($N = 26$). Table 3 shows the results of the ANCOVA in which the dependent variable was O_3 achievement; the covariate was O_2 achievement and the independent variables were group (Early or Late), number of CLIPS completed (none, some or all) and the interaction between CLIPS completed and group. We found an interaction: the number of CLIPS completed made a difference for the Late Treatment group (who completed CLIPS during the O_2 to O_3 period) but not for the Early Treatment (who were not working on CLIPS during the O_2 to O_3 period). The means indicated that students who completed all the five CLIPS improved more than the students who completed some or none: Cohen's $d = 0.32$ for the all CLIPS versus none comparison and $d = 0.16$ for the all versus some comparison.

5.7. Study 1 discussion

Study 1 found that CLIPS had a statistically significant effect on student achievement in the Late but not the Early Treatment group. The most likely explanation is that unforeseen technology-related challenges could not be overcome

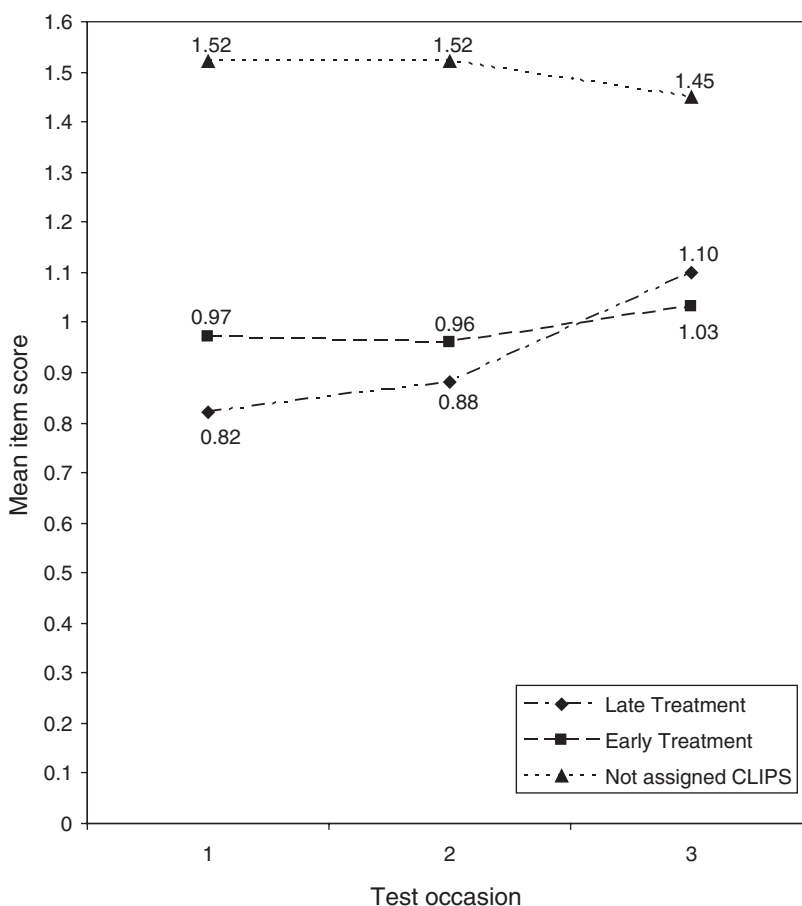


Figure 1. Student achievement by test occasion and Study 1 condition.

by the first group of teachers using CLIPS. By the time of the second round, implementation problems had been identified and teachers could draw on their colleagues for strategies to reduce technical problems and the need for greater support for students working on CLIPS. For example, CLIPS was loaded on the district server so that students avoided problems of the web-based version and had to work on the program in school.

We also found that the effects of CLIPS were stronger if students completed all the five CLIPS. Even though CLIPS were designed to be an individualized program, teachers tended to assign each CLIPS to a particular day, e.g. A = Monday, B = Tuesday, etc. If students were absent on a particular day, teachers typically had them skip that CLIPS if it had been assigned to them and continue with the next CLIPS scheduled on the day of their return. We found many instances of completed CLIPS sequences that were not likely planned by teachers, e.g. A–B–E or B–D.

In Study 2 we investigated these issues further. We were particularly interested in determining whether the number of CLIPS completed influenced student performance.

Table 3. The effects of group assignment and number of CLIPS on O₃ achievement in Study 1.

Source	SS	df	MS	F	Sig.	(Partial Eta) ²
Corrected model ^a	34.87	6	5.81	105.97	<0.001	0.640
Intercept	9.23	1	9.23	168.21	<0.001	0.320
None-some-all CLIPS ^a group	0.55	2	0.27	5.01	0.007	0.027
None-some-all CLIPS	0.11	2	0.05	0.96	0.384	0.005
Group	0.12	1	0.12	2.27	0.133	0.006
O ₂ mean	23.11	1	23.11	421.28	<0.001	0.541
Error	19.58	357	0.05			
Total	720.84	364				
Corrected total	54.45	363				

Note: ^a $R^2 = 0.640$ (Adjusted $R^2 = 0.634$).

6. Study 2

6.1. Study 2 methodology

Study 2 was a pre-post single group design in which the dependent variable was posttest achievement, the covariate was pretest achievement and the independent variable was number of CLIPS completed (0, some, or all five). Participants were 307 grade 7 students in 18 classrooms from the Catholic school district that was co-terminus with the public school district participated in Study 1. The two districts served overlapping regions with virtually identical student population characteristics: 98% were Canadian born, less than 1% spoke a language other than English at home, 26% were identified as special needs and average family income in the district was near the mean for the province of Ontario.

The sources of data were the same achievement tests administered in Study 1 and the number of CLIPS completed by students as reported by their teachers. Teacher training included the information given to Study 1 teachers, except that Study 2 teachers were given specific guidance, drawn from Study 1, in how to optimize implementation. There were three sets of conditions [30]: students (e.g. encourage students to think of their assignment to CLIPS as a reward or learning opportunity rather than a punishment), technical (e.g. ensure that all students have headphones) and teaching (e.g. provide a warm up that matches the procedural and conceptual focus of CLIPS).

6.2. Study 2 results

There were no missing data. Both achievement scales were reliable ($\alpha = 0.71$ and 0.78 , respectively) and normally distributed (skewness = -0.918 and -1.208 ; kurtosis = -0.116 and 1.369). We grouped the number of CLIPS assigned into the three categories of use developed for Study 1: none, some (i.e. 1–4) and all. Teachers assigned at least one CLIPS to 42% of their students. The pretest and posttest means for each student group are shown in Table 4.

Table 4 shows that there was virtually no change from pre to posttest for the groups that received no CLIPS or less than five CLIPS, in contrast with the means for the group that completed all five. We conducted an ANCOVA in which the

Table 4. The pre- and posttest means of students assigned CLIPS in Study 2.

	<i>N</i> CLIPS	<i>N</i> Students	Mean item score	SD
Pretest	None	178	1.48	0.51
Pretest	Some	90	1.46	0.45
Pretest	All	39	1.27	0.56
Posttest	None	178	1.48	0.39
Posttest	Some	90	1.47	0.35
Posttest	All	39	1.52	0.35

Table 5. The effect of number of CLIPS and pretest scores on posttest student achievement in Study 2.

Source	SS	df	MSS	<i>F</i>	Sig.	(Partial Eta) ²
Corrected Model ^a	17.36	3	5.785	81.294	<0.001	0.446
Intercept	22.41	1	22.409	314.900	<0.001	0.510
pretest	17.28	1	17.284	242.888	<0.001	0.445
No. CLIPS	0.68	2	0.340	4.782	0.009	0.031
Error	21.56	303	0.071			
Total	714.82	307				
Corrected total	38.92	306				

Note: ^a $R^2 = 0.446$ (Adjusted $R^2 = 0.440$).

outcome variable was the student achievement posttest, the covariate was the student achievement pretest score and the independent variable was the number of CLIPS assigned. Table 5 shows that after controlling for pretest effects, there was a statistically significant effect for CLIPS: students who were assigned all the CLIPS outperformed students who were assigned none or less than the complete package. The within-subjects effect sizes were $d=0.0$ for students receiving no CLIPS, $d=0.02$ for students receiving less than five CLIPS and $d=0.53$ for students completing five CLIPS.

6.3. Study 2 discussion

Study 2 replicated the findings of Study 1: completion of all five CLIPS contributed to student achievement, but completion of less than five had no effect. The effect sizes were larger than in Study 1, increasing from $ES=0.30$ in the late treatment of Study 1 to $ES=0.53$ in Study 2. Our interpretation is that the technology-related difficulties students encountered in Study 1 and the lack of supervision/support they received made it doubtful that students completed CLIPS as intended. For example, some students may have entertained themselves by manipulating the flashier aspects of the program without engaging in serious learning. The teachers in the Study 2 sample had the benefit of this experience and were able to reduce the problems.

7. General discussion

The two studies demonstrate that learning objects completed by students with relatively little teacher direction can improve student performance on fraction tasks

that are difficult to learn. The effect sizes were modest, when compared to the results of efficacy studies of treatments implemented in optimal conditions. Our studies, although they used volunteers (required by our ethical review protocol) approximated effectiveness studies because we did not screen the teachers, teacher training on the use of the CLIPS was minimal and no additional hardware was provided to the schools. For example, the CLIPS effect sizes for Study 1 late treatment ($ES = 0.30$) and Study 2, $ES = 0.53$, compare favourably to the median $ES = 0.50$ in a study of 300 meta-analyses of educational and psychological interventions [37] and to the $ES = 0.15$ for all comprehensive school reform programs in the meta-analysis of Borman *et al.* [38] and $ES = 0.11$ for all Title I programs for schools serving disadvantaged students [39].

The key finding of this study was that students needed to complete all five CLIPS. We suggest three reasons: (1) student absences had negative effects, in part because teachers unnecessarily aligned CLIPS with days of the week. Students who missed a CLIPS to which they were assigned did not make it up. (2) The storyboards for the CLIPS followed an instructional sequence based on research on fractions learning [27–29]. Incomplete sequences deprived students of instruction in one or more constructs linked to other key ideas in the conceptual map. (3) The entire sequence involved modest amounts of instructional time (5×20 min). Incomplete sequences provided insufficient practice to remediate student misconceptions.

The two studies highlight the importance of evaluating the effects of technology interventions through a program of research, rather than one-shot summative evaluations. Researchers are too quick to generalize from a single evaluation [40]. Even though we pilot tested an earlier version of CLIPS, neither we nor our practitioner partners anticipated the severity of the hardware and software challenges that teachers would face when the program was rolled out to a larger group of classes. If we had focused exclusively on the results from the Early Treatment group in Study 1, we would have concluded that the program had no student achievement effects. It was only when the implementation issues were reduced that student benefits began to emerge.

8. Conclusion and limitations

We were not able to implement a true experiment as we had intended in Study 1. Genuine experiments are the gold standard in educational research and provide greater protection from internal validity threats than quasi-experiments [41], although establishing causality is challenging even within experimental designs [42]. In Study 1, unforeseen difficulties in implementing study conditions resulted in serious attrition, which required that we treat the design as a pre-post quasi-experiment with matched controls. Quasi-experiments provide useful information provided there is evidence of the equivalence of groups on entry to the study and an appropriate predictor of achievement (the most powerful is prior achievement) is included as a covariate [43]. We provided evidence of pretest group equivalence and included prior achievement as a covariate. Slavin and Lake [44] in a best-evidence synthesis of elementary math programs reported that only 36 of the 87 they included as high-quality studies used random assignment.

The task of developing effective learning sequences both online and offline is worth continuing effort. Fractions are difficult for students to learn, there is relatively little attention to them in the high school years, and flaws in performing simple fractions tasks can have moderate to severe consequences in adult life. The findings of our research to date suggest that CLIPS are promising: students who completed the sequence of five CLIPS improved their understanding, using modest amount of instructional time and only modest teacher intervention.

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